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THE EFFECT OF IMPOSING 1 TO 2 YEARS OF TILLAGE ON LONG-TERM NO-TILL SOILS ON CARBON SEQUESTRATION

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"The effect of imposing 1 to 2 years of tillage on long-term no-till soils on carbon sequestration, soil-water conservation, plant nutrient management and crop production".

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Mike Grevers

Abstract

During the last two decades, an increasing number of producers have adopted a no-tillage or minimum tillage system because of the potential to reduce soil erosion, conserve soil moisture, improve soil structure and increase net returns. No-tillage systems also store significantly more soil organic carbon, enhance microbial activity, aggregate stability, and water infiltration rates than multiple pass tillage systems.

Potential concerns related to elimination of tillage, include stratification of nutrients near the soil surface and lack of herbicide options to control certain weeds. These concerns have lead some producers to consider applying one or more cycles of tillage to their no-till fields. Little information exists on the impact of imposing one or more tillage operations on a long term no-till soil. Therefore a study was conducted to examine the effect of tillage on soil conditions at three long-term no-till sites, one in each of the Brown, Black, and Gray soil zones of Saskatchewan. The sites were previously managed as no-till for 10 years or more. During this study the sites were subjected to a one year (cycle) of tillage at three levels of intensity involving spring only, fall + spring, and fall + spring + disc and a no-till control.

Soil cores were taken in the spring after imposition of the tillage treatments. The cores were then incubated to assess soil microbial activity and nutrient supply rates. No-tillage plots produced the lowest CO_2 flux during incubation, while treatments that included different levels of tillage produced higher levels of CO_2. However, the intensity of the tillage treatments did not necessarily correspond with the amount of CO_2 produced. The tillage treatments affected the rate of release of inorganic N. At the site in the Brown soil zone on chemical fallow, tillage treatments increased the supply rate of nitrate. However, incorporation of fresh cereal straw with tillage at the Black and Gray soil sites immobilized some plant available inorganic N. Tillage reduced the bulk density of the surface soil. Soil temperature measurements taken shortly after the spring tillage operations revealed approximately a 1 °C increase in soil surface temperature associated with tillage. Only a single tillage treatment was needed to see the warming effect. Total soil organic matter concentration, particulate organic matter, pH, EC, and mean weight diameter of the soil aggregates generally were not significantly affected by the tillage operations. There was evidence that tillage reduced nutrient stratification. There were no yield differences due to the tillage treatments at the Central Butte site in the Brown soil zone while the Rosthern site in the Black soil zone some yield increases occurred, which may be attributed to nitrogen (N) mineralization. The Tisdale site in the Gray Soil Zone experienced some yield reductions due to N immobilization.

The imposition of one cycle of tillage on long-term no-till soils does not appear to have a major impact on soil properties or crop growth. However, trends in the results suggest that more frequent tillage (2 or more years of continuous tillage) have the

potential to effect soil properties and therefore crop production. Furthermore, the research was carried out on small field plots, which means that there was little opportunity to study the effect of tillage on soil erosion.

"The effect of imposing 1 to 2 years of tillage on long-term no-till soils on carbon sequestration, soil-water conservation, plant nutrient management and crop production".

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Final Progress Report

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1. Introduction

Over the past two decades reduced tillage or no- till has become a widely accepted practice across the Prairies. The beneficial effects of reduced tillage are well documented and include increased soil organic carbon contents, greater soil and water conservation and in many instances increased crop production and reduced inputs. Reduced tillage has also resulted in improved soil quality and improved soil structure. It has resulted in carbon sequestration and reducing the amount of CO_2 emissions in Canada since 1990 (Bruce et al, 1999; Liang et al, 1997).

The trend towards more reduced tillage may become reversed in some areas, at least temporarily, as producers struggle with high input costs (especially fertilizers and herbicides) and low commodity prices (Larry Gutek, personal communication). The proliferation of weeds with few or no herbicide control options such as for foxtail barley, concerns over nutrient stratification at the soil surface and slow soil warming in spring may lead producers to consider one or two years of mechanical tillage in their no-till systems. Producers need to know if periodic tillage under no-till conditions can be implemented without losing much of the benefit of no-till on the quality and productivity of their lands.

The long-term effect of conventional tillage on soil quality is well documented. Numerous articles have shown that prairie soils lost up to half the original soil organic matter within 40 to 50 years since the soils were first cultivated (Bruce et al, 1999), and much of these losses occurred during the first decade.

Reduced tillage, especially zero-till, has halted or even reversed the decline in soil organic matter (Campbell et al, 1995; Elliott and Efetha, 1999). Liang et al. (1999) reported that with the elimination of both tillage and fallow, soil organic C increased 200 kg C ha^{-1} yr^{-1} in the Brown soil zone and from 600 to 800 kg C ha^{-1} yr^{-1} in the Dark Brown and Black soil zones. Relative annual increases were dependent on soil clay content. The improvement in soil conditions includes better soil structure (Elliott and Efetha, 1999). Carter et al. (1992) reported that in no-till, the soil pore system is made up of fewer but more continuous macropores. A more continuous soil macropore system allows for improved water infiltration and reduced water erosion.

Long-term no-till farming systems have resulted in increased carbon sequestration, and soil organic carbon levels have increased by as much as 1.5 Mg ha^{-1} (Bremer et al, 2002).

Much of the gain in soil organic matter is in the mineralizable and light fraction material, and this portion may be rapidly lost when no-till soils are reverted back to conventional till farming systems. Furthermore, compared to conventional till soils, the organic matter of no-till soils is generally more concentrated near the surface (Carter et al., 1992).

Conventional tillage on zero-till soils would incorporate surface residues where decomposition is more favourable (greater moisture content and greater microbial activity), it would also disrupt soil aggregates, which protect soil organic matter from decomposition, and it would stimulate microbial activity through enhanced aeration (Schoenau and Campbell, 1996). Furthermore, spring surface soil temperatures can be up to 7 ^{o}C warmer under conventional tillage (Moulin et al. (2000). As a consequence of the above, conventional tillage would increase the rate of organic matter decomposition, and therefore increase mineralization of plant available nutrients such as N and S. Initially the increase in soil microbial activity would produce polysaccharides etc., which promote soil aggregation. Soil and water conservation would likely decrease due to the incorporation of surface residues and the disruption of the soil-pore system, and this may limit the beneficial effect of the improved soil fertility on crop production. It is not clear if the above changes would result in a dramatic effect in the first year or would involve a more gradual change over a two to three year period such as the case with increased nutrient levels when farm manure is applied to fields (Grevers and Schoenau 1998).

The purpose of this project is to study the transformations to soil chemical and physical conditions and crop production after long-term no-till soils are cultivated by traditional methods for one cycle. The results will demonstrate the significance of reverting no-till soils back to conventional (mechanical tillage) for a short period of time. This information will help producers plan their crop rotations and adjust fertilizer and other inputs. Furthermore, the results will indicate the feasibility of maintaining conventional tillage equipment.

2. Objectives

The objective of this project is to study the effect of tillage on soil conditions and crop production in fields that have been previously managed as no- till for at least 10 years, and are subjected to one cycle of different levels of tillage. The soil conditions and crop growth will be monitored during the field season when the tillage cycle is applied and during two subsequent field seasons when the fields are returned to no till.

3. Materials and methods

Three field research sites were selected, one in each of the Brown, Black and Gray soil zones. Each field had been previously farmed as a NT production system for 10 to 12 years. The site in the Brown soil zone is located near Central Butte, the site in the Black soil zone is near Rosthern, and in the site in the Gray soil zone is near Tisdale SK. Four tillage treatments identified as no-till (NT), minimum-till (MT), conventional till (CT), and maximum till (MXT) were imposed on plots with dimensions of 7.3 m x 15.2 m. A completely randomized treatment design replicated four times was used in this study. The control treatment (NT) had no pre-seeding tillage. The minimum tillage treatment (MT) was subjected to a single tillage operation in the spring of 2005 using a 1.8 m cultivator

equipped with 30 cm sweeps and a 30 cm row space, operating at a depth of approximately 7 to 8 cm and a travel speed of 6.4 km h^{-1}. The conventional tillage treatment (CT) included a fall tillage operation in 2004, followed by a spring tillage operation in 2005 using a cultivator. The "black" or maximum tillage treatment (MXT) included a fall 2004 and spring 2005 cultivation followed by an additional tillage operation using a tandem disc with notched blades traveling at 6.4 km h^{-1}. (The tillage treatments were carried out with the same cultivator and disc at all sites in the fall of 2004 and the spring of 2005. In the spring of 2007, the field plots were divided in half to allow a second set of tillage treatments MT-2 and MXT-2. The complete set of tillage treatments is shown below (pictures of the tillage operation are shown in Appendix Table 1).

Tillage treatments

NT	No-Till
MT	Min Till (cultivated in spring 2005)
CT	Conventional Till (cultivated in fall 2004 and in spring 2005)
MXT	Max Till (cultivated in fall 2004 and in spring 2005, and disked in spring 2005)
MT 2	Min Till (cultivated in spring 2005, and in spring 2007)
MXT 2	Max Till (cultivated in fall 2004 and in spring 2005, and disked in spring 2005, and disked in spring 2007

3.1 Site Characteristics

3.11 Central Butte site

The research site near Central Butte, SK (legal location: NW 30-20-3 W3) had been previously cropped in a cereal chem-fallow rotation using NT for 10 years. The site is located in the Brown soil zone and is classified by Saskatchewan soil maps as a mixture of Kettlehut and Ardill soil associations. The Kettlehut soil association is predominantly a Brown Solod to a Brown Solodized Solonetz, and the Ardill soil association is dominantly an Orthic Brown to a Calcareous Brown Chernozem. The parent material is moderately fine textured, moderately calcareous, glacial till. The landform is glacial till plains with knolls and depressions. The slope class is gently sloping or undulating. The stone class is stated as moderately stony. Particle size analysis at this location indicated a loam soil texture.

After the tillage treatments the field was seeded to Hard Red Spring Wheat (*Triticum aestivum* L. cv Prodigy) in early May of 2005 using a John Deere air seeder equipped with 40 cm sweeps. The seeding rate was 94 kg ha^{-1} and a fertilizer blend with an analysis of 28-26-0 was seed placed at a rate of 67 kg ha^{-1}.

3.12 Rosthern site

The Rosthern site is located in the Black soil zone (legal location: SW 3-43-02 W2) on the Seager Wheeler farm. The site had been continuously cropped using a NT cereal-oilseed rotation for the last 12 years. Saskatchewan soil maps describe this site as a Hamlin Orthic Black soil association with very fine loam to loam soils. The landform is a shallow lacustrine plain with knoll/depression patterns and gently sloping or roughly undulating slope class. The soil texture is a medium loam.

After the tillage treatments, the field was seeded to canola (*Brassica napus* L. cv. Banner) at 6.2 kg ha^{-1} with a side-banded fertilizer blend containing 56 kg ha^{-1} actual N, 22.4 kg ha^{-1} of actual P_2O_5, and 11.2 kg ha^{-1} of actual S using a Seed Hawk air-drill with a 1.27 cm knife opener in late May of 2005.

3.13 Tisdale site

The research site in the Gray soil zone is located near Tisdale, SK (**Error! Reference source not found.**) (legal location: SW2-47-14 W2). The site has been continuously cropped using a NT cereal-oilseed rotation for the last 12 years. Saskatchewan soil maps describe this site as mixture of Eldersley and Tisdale soil associations with mainly Gray Wooded Eldersley soils on the uplands, including the research plot area, and Orthic Tisdale soils on lower slopes and through the depressions. The soil texture is silty clay with a gently sloping slope class with slopes dominantly ranging from 2 to 5% that producing hummocky inclined landforms. The soil texture at the plot site is medium silty clay loam to clay loam.

After the spring tillage treatments the site was seeded to canola (*Brassica napus* L. cv. Millenium) at 5.6 kg ha^{-1}, fertilized with a blend of 67.2 kg ha^{-1} actual N, 22.4 kg ha^{-1} of actual P_2O_5 and 22.4 kg ha^{-1} of actual S using a Flexicoil 5000 airdrill with 7.5 cm Stealth Single Shoot openers. Half the N was put down mid-row as NH_3 and the rest was put down as dry granular along with granular P and S.

3.2 Field plots

In the fall of 2004, prior to the tillage treatments, the field sites were sampled along a transect bisecting the corners of each plot. A truck mounted hydraulic coring unit was used to take five soil samples per plot at a 3.4 m sampling interval to a depth of 60 cm. These soil samples were segmented into 30 cm lengths and analyzed for particle size distribution by the pipette method (McKeague, 1976). These samples enabled an evaluation of parent material uniformity across the experimental site. Particle size fractions were calculated as percent by weight taking into account the amount of $NaPO_3$ added to the samples.

3.3 Sample and sample preparation

Plots were measured out in preparation for the tillage treatments as previously described. After the spring tillage operations were completed in the last week of April, 2005 and before seeding each tillage plot was immediately sampled with a polyvinyl chloride (PVC) pipe punched down to a depth of 15 cm. The PVC pipes provided an intact soil core measuring 10 cm in diameter and 15 cm in depth. Three cores were removed from each plot. After extraction, the cores were transferred to plastic bags and then placed in an insulated container. The cores were transported to the University of Saskatchewan and stored at 4 °C. Prior to processing, the cores were subjected to a two week incubation at field moisture content to measure nutrient supply rates immediately following tillage. The incubation allowed the soil core temperatures to stabilize prior to measuring the soil properties. After incubation the soil cores were segmented into 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm depth increments for further analysis of soil properties. The corresponding depth segments from three subsamples of each plot were bulked and air dried before being ground to pass through a 9 mesh (2 mm) sieve.

3.31 Soil organic carbon analysis

Soil organic C was determined on using the top 5 cm soil core increments using a LECO CR-12 C Analyzer (Wang and Anderson, 1998). Prior to analysis the soil was ground to pass through a 2 mm sieve. A 0.15 g sub-sample was placed into the LECO furnace at a temperature of 840 °C. Soil C was calculated using the equation developed by Ellert and Bettany (1995).

3.32 Particulate organic matter

Particulate organic matter (POM) is a dynamic and easily oxidizable part of soil organic matter. Hussain et al. (1999) reported that POM is an early indicator of SOC changes and is the most tillage sensitive fraction of organic mater. Particulate organic matter was therefore measured at the soil surface (0 to 5 cm) of all treatments. Particulate (>53μm) and mineral-associated organic matter (<53 μm) were separated from each aggregate size fraction by sieving after mechanical dispersion of the soil by agitation in water with glass beads according to the procedure outlined by Balesdent et al. (1991) as cited in Aoyama et al. (1999). The dispersed POM plus sand was collected on the surface of a 53-μm sieve and washed with 340 mL deionized water. The material > 53 μm was dried in a forced-air oven at 40°C and weighed. The weight of particles > 53 μm in each aggregate size fraction was determined by the difference between the weight of undispersed particulate (> 53 μm) aggregates and that of the material in the < 53 μm size fraction. The content of total C in the mineral-associated organic matter (<53 μm) was directly determined by the LECO CR-12 Carbon Analyzer (Wang and Anderson, 1998).

3.33 Soil temperature

During core sampling a Pronto Plus™ thermocouple temperature gauge (Thermo Electric, Saddle Brook, NJ) was used to measure soil surface temperatures in the field. The Pronto Plus™ was calibrated in water. Ice was added to a glass of water to cool it to 0 °C and then the thermocouple wire was inserted into the cool water and calibrated. Holes were made in the field soil surface with a bamboo stick measured to a 5 cm depth after the tillage treatments were imposed. The thermocouple wire was then inserted into the hole and left to equilibrate to the plot soil temperature for five minutes. After five minutes the temperature was recorded.

Midway through June, after the Rosthern site had been seeded, four Hobo® H8 Pro Series temperature probes were used to measure temperature differences in the NT and MXT treatments. Two probes were buried at random in a NT control plot and in a MXT plot. The probes were installed so that the surfaces of the temperature gauges were in full contact with the soil. Soil temperature measurements were made every six seconds for six days. Data were downloaded to a laptop computer using Onset Computer Corporation's BoxCar® Pro 3.5 or BoxCar® 3.6 software after the probes buffers became full.

3.34 Soil aggregation

Soil aggregation was assessed using the technique outlined by White (1993). Bulk hand samples were collected using a shovel and placed in a plastic bag for transport. The hand samples were subsequently air dried and placed in a rotary sieve with openings of 53.53

mm, 34.58 mm, 17.51 mm, 7.20 mm, 2.58 mm, 1.30 mm, and 0.50 mm. Mean weight diameter (MWD) was calculated using the following equation:

3.35 Soil pH and electrical conductivity

pH and electrical conductivity (EC) were determined following the technique of Hendershot and Lalande (1993) and Janzen (1993). The resulting 2:1 distilled water to soil suspension was analyzed for pH and EC with a Beckman 50 pH meter and a Horba ES-12 conductivity meter.

3.36 Soil nutrient extractions

Inorganic N was extracted using 2*M* KCl following the procedure of Keeney and Nelson (1982) and analyzed using a Technicon™ Auto-analyzer sampler II; AAII single channel colorimeter with 1.5 (id) x 30 mm tubular flowcell, 420 nm interference filter, and voltage stabilizer and recorder (Tenchnicon Industrial Systems, Tarrytown, NY 10591)

A modified Kelowna (MK) extraction procedure was used to extract P and K as outlined by Qian et al. (1994a) and the extractant was colorimetrically analyzed using the Technicon™ Auto-analyzer sampler II.

3.37 Crop yield sampling

Above ground crop samples were taken in the fall of 2005 just before the producer swathed the plot site. Sampling of each plot was conducted by using a 1 m^2 quadrat to obtain two biomass subsamples. Plants were harvested approximately 7.62 cm above the ground to simulate a swather cut level. Samples were placed in cotton bags and air dried. After drying the harvested plant material was weighed to obtain biomass yields. The plant material was processed through a threshing machine. The resulting seed was cleaned, weighed and grain yields recorded for each plot. A small amount of straw was kept for digestion and extraction to determine straw nutrient uptake.

3.38 Grain and nutrient uptake

Total plant P and N concentrations were determined on grain and straw samples using a standard H_2SO_4-H_2O_2 digestion method (Thomas et al., 1967). Total P and N concentrations were colorimetrically determined with the Technicon™ Auto-analyzer (Tarrytown, NY). Total plant nutrient uptake was determined by multiplying the grain and straw nutrient concentrations by grain and straw yield.

3.39 Soil CO_2 gas measurements

PVC cores (10 cm in diameter and 15 cm long) (Appendix B) were used to take intact soil core samples from each treatment plot in the spring of 2005 immediately following imposition of the tillage trials in late April. The intact soil cores contained within the PVC pipe were removed from the field and stored at 4 °C. The cores were placed in an incubation chamber with electronically controlled environmental settings. The chamber was set for 16 h at 25 °C (day) and 8 h at 18 °C (night). The cores were incubated for 1 week at field moisture content after which 32 mL of water were poured on to the surface of the soil cores using a graduated cylinder to simulate a light rainfall. The added water produced a wetting front of 3 mm. The cores were then incubated for another week. Due to space restrictions only one site was incubated at a time.

Carbon dioxide gas sampling.

The incubation experiment consisted of intact PVC cores placed into a two part container made up of two PVC pipes 15 cm in diameter and 15 cm long and two sewer caps (Nelson, 2003). The two-part PVC container was joined together by a rubber airtight flange fastened with hose clamps. A rubber septum was inserted into the probe inserted into the core inside of an uncovered chamber. The PVC containers were capped and sealed daily for 1 h. A syringe needle (20 cm^3) was placed through the rubber septum and was used to transfer a 20 cm^3 gas sample into an evacuated vial (10 cm^3) every day at the same time for two weeks. Before sampling commenced, three ambient 20 cm^3 CO_2 samples were placed into three 10 cm^3 evacuated vials to make sure if there was gas leakage that it was out of the container instead of in. After sampling, the tops of the PVC containers were removed to allow natural airflow between the chamber and the intact soil cores. A sealed chamber containing an intact soil core with a syringe inserted into a septum ready for gas sampling.

Field CO_2 sampling

One-time field gas samples were taken with a two-part chamber system at Rosthern after seeding in mid-June of 2005. An aluminum ring was installed in the tillage treatment a week before sampling so as not to disturb the soil microorganisms and cause a flush of CO_2. Sampling commenced 20 min after the top part of the chambers were connected to the aluminum rings installed in the soil. Sampling was completed in the same manner as was done in the electronically controlled incubation protocol of the intact soil cores. Gas samples were processed with the same equipment and procedure as was done with the incubation gas samples outlined below.

Gas analysis

Carbon dioxide concentrations were determined using a Varian CP-2003 micro-GC with twin micro-thermal conductivity detectors. An on-board vacuum pump pulled the sample into a He gas stream with an injector temperature of 110 °C. The sample CO_2 was separated using a Hayesep column at 50 °C.

3.4 Statistical analysis

This experiment was set up as a completely randomized design. A significant ANOVA result indicates that at least one of the mean treatments was different (Zar, 1999). Mean separation was done using least significant difference (LSD) at an $P = 0.10$ unless otherwise stated (SPSS, 2005).

4 Results and discussion

4.1 Soil physical properties

Tillage decreased the soil BD compared to the NT control at Central Butte and Rosthern sites (Table 3). This corresponds with the findings of Franzluebbers (1995a) where soil BD was reduced by tillage. The BD measured at Tisdale was too variable to show a significant tillage effect, although there was a trend of decreased soil BD with increasing tillage at the 5 to 10 cm depth (Table 1).

Available soil moisture and temperature have a large effect on microbial processes, including mineralization and immobilization rates (Havlin et al., 2005). No significant differences in moisture and temperature due to the tillage treatments were observed in the spring prior to seeding.

Generally there was a slight increase in soil temperature (≈ 1°C) in the 0 to 5 cm depth induced by tillage. This may have had an effect on the rate of mineralization-immobilization processes before seeding at Central Butte, Rosthern and Tisdale. Temperature differences, monitored with the Hobo™ temperature probes tended to persist between the NT and MXT treatments.

Tillage did not effect soil aggregation (Table 2). A one-cycle of tillage may be insufficient to cause in enough disruption of soil aggregates.

Table 1. Soil physical properties, spring 2005.

Item	Depth	Tillage Treatments				Significance	
	cm	NT	MT	CT	MXT	Prob.	$LSD_{0.05}$
Central Butte							
MWD, mm	0-15	9.0	12.7	10.2	12.3		
Bulk Density	0-5	1.12	1.08	1.06	1.07		
Mg/m^3	5-10	1.43	1.20	1.25	1.21	5%	0.20
	10-15	1.26	1.26	1.32	1.21		
	0-30	1.47	1.667	1.43	1.39		
	30-60	1.67	1.68	1.71	1.77		
SWC (%)	0-5	0.25	0.24	0.22	0.30		
	5-10	0.17	0.13	0.14	0.14		
	10-15	0.17	0.15	0.17	0.15		
	15-30	0.36	0.49	0.50	0.39		
	30-60	0.27	0.28	0.35	0.36		
cm's of water	0-60	15.6	17.6	19.7	18.4		
Soil temp. °C	0-5	16.5	17.5	17.3	17.5		

Table 1. Soil physical properties, spring 2005 (continued).

Item	Depth	Tillage Treatments				Significance	
	cm	NT	MT	CT	MXT	Prob.	$LSD_{0.05}$
Rosthern							
MWD, mm	0-15	20.6	19.6	21.0	22.5		
Bulk Density	0-5	1.07	0.98	1.02	0.94		
Mg/m^3	5-10	1.27	1.23	1.08	1.06	**1%**	0.06
	10-15	1.06	1.02	1.05	1.17		
	0-30	1.38	1.37	1.38	1.42		
	30-60	1.44	1.40	1.42	1.38		
SWC (%)	0-5	0.11	0.09	0.09	0.08	**1%**	0.02
	5-10	0.21	0.21	0.18	0.18		
	10-15	0.18	0.17	0.17	0.19		
	15-30	0.36	0.39	0.44	0.40		
	30-60	0.22	0.22	0.25	0.24	5%	0.02
cm's of water	0-60	14.54	15.00	16.24	15.37		
Soil temp. ^{o}C	0-5	14.13	14.28	15.15	15.30		
Tisdale							
MWD, mm	0-15	24.4	18.9	22.3	20.2		
Bulk Density	0-5	0.81	0.82	0.81	0.90		
Mg/m^3	5-10	1.20	1.04	1.01	0.96		
	10-15	1.20	1.25	1.19	1.13		
	0-30	1.49	1.41	1.44	1.45		
	30-60	1.61	1.56	1.58	1.56		
SWC (%)	0-5	0.10	0.08	0.11	0.09		
	5-10	0.27	0.20	0.18	0.33		
	10-15	0.28	0.23	0.21	0.20		
	15-30	0.45	0.56	0.50	0.49		
	30-60	0.40	0.40	0.42	0.40		
cm's of water	0-60	21.9	23.0	22.4	22.4		
Soil temp. ^{o}C	0-5	13.0	25.3	13.4	16.2	5%	2.7

Table 2. Mean weight diameter of aggregates from hand collected soil samples taken after imposition of tillage treatments.†

Treatment	Central Butte	Rosthern	Tisdale
		mm	
NT	8.98	20.59	24.37
MT	12.69	19.62	18.85
CT	10.24	21.01	22.32
MXT	12.31	22.54	20.29
$LSD_{(0.10)}$	NS‡	NS	NS

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at P = 0.10

4.2 soil Organic Matter

Soil C is a key factor affecting soil productivity and represents a significant pool of stored C in the ecosystem (Schlesinger, 1997; Schoenau and Campbell, 1996). The imposition of one (MT), two (CT), or three (MXT) tillage operations in this study did not have a significant impact on the amounts of TOC and the fraction of TOC identified as POM (Tables 3 and 4). This is probably due to the fact that one cycle of tillage is not enough to induce the accelerated decomposition and erosion that has been reported to result in significant decline in TOC after several years of tillage (Wu et al., 2006). However the trend of decreasing concentration of TOC and POM that was observed could become significant if the treatments were continued over a number of years (Jenkinson and Rayner, 1977).

Rather unexpectedly, the POM C fraction did not show a significant difference among tillage treatments (Table 4). Although it has been noted that POM (sand plus organic matter) is the fraction of organic matter most sensitive to management, including tillage (Hussain et al., 1999; Wu et al., 2006), we did not see a tillage effect after one cycle of tillage. Variability in POM in the field due to uneven distribution of residue during the harvesting process and uneven distribution created by sample processing may have contributed to results that were too variable to reveal significant differences in POM between the tillage treatments.

Organic C plays a major role in binding soil aggregates together (Tisdall and Oades, 1982). The lack of significant effects of the tillage treatments on aggregation is consistent with no major changes in TOC or POM. Overall, one cycle of tillage involving one, two or even three successive operations does not appear to have a large impact on total surface soil C or recent sand sized C fractions in the form of POM. Wu et al. (2006) observed that 7 years of NT was required to produce a gain of 0.1 Mg C ha^{-1} in the sand sized fraction of the 0 to 5 cm layer at the Central Butte site. One cycle of tillage imposed on the NT soil did not decrease SOC significantly.

Table 3 Spring and fall total organic carbon mass (Mg C ha^{-1}) in intact soil cores taken after imposition of tillage treatments in segments of 5 cm to a total depth of 10 cm.†

Treatment	Central Butte			Rosthern			Tisdale		
	0-5 cm	5-10 cm	0-10 ‡ cm	0-5 cm	5-10 cm	0-10 cm	0-5 cm	5-10 cm	0-10 cm
	Spring 2005								
	Mg ha^{-1}								
NT	7.68	8.38	16.59	15.08	17.26	32.34	16.92	19.19	36.10
MT	7.62	7.17	14.78	14.43	16.85	31.27	14.36	15.58	29.94
CT	7.12	7.34	14.46	14.28	15.06	29.34	13.62	15.26	28.88
MXT	7.12	8.21	15.33	13.74	15.00	28.74	15.71	14.63	30.34
$LSD_{(0.10)}$	**NS§**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	Fall 2005								
NT	7.59	7.98	15.39	14.36	16.24	30.60	16.35	18.52	34.87
MT	7.02	7.05	14.07	12.83	15.16	27.99	14.92	14.24	29.16
CT	7.23	7.70	14.93	12.84	14.21	27.05	12.35	13.92	26.27
MXT	8.13	7.97	16.10	12.56	13.73	26.29	14.86	13.71	28.57
$LSD_{(0.10)}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring cultivator tillage; CT: fall and spring cultivator tillage; MXT: fall, spring cultivator tillage and spring disc tillage; LSD: least significant difference

‡ Measurement of the 10 to 15 organic carbon mass was not done as the BD for this segment could not be calculated due to uneven breakage at the core base during extraction.

§ Not significant at P = 0.10

Table 4 Carbon in particulate organic matter fraction from the top 5 cm of the intact soil cores taken after the imposition of tillage treatments.†

Treatment	Central Butte		Rosthern		Tisdale	
	Spring	Fall	Spring	Fall	Spring	Fall
	mg/Mg					
NT	11.6	9.30	21.4	19.9	44.8	46.8
MT	10.6	8.80	22.2	21.1	38.4	39.7
CT	10.0	8.60	20.7	20.1	36.3	36.0
MXT	11.3	10.4	22.3	19.5	36.5	38.1
$LSD_{(0.10)}$	**NS‡**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring cultivator tillage; CT: fall and spring cultivator tillage; MXT: fall, spring cultivator tillage and spring disc tillage; LSD: least significant difference

‡ Not significant at $\alpha = 0.10$

4.3 CO_2 evolution

All three sites showed that the soil that was not tilled produced the least amount of CO_2 (Appendix C). Tillage exposes organic matter to attack from microorganisms and thus produces higher fluxes of CO_2 due to increased microbial activity and decomposition rates

4.4 Soil chemical properties.

There were no effects on the soil chemical properties (Table 5).

Table 5. Soil chemical properties in spring 2005.

Item	Depth	Tillage Treatments				Significance	
	cm	NT	MT	CT	MXT	Prob	$LSD_{0.05}$
Central Butte							
pH	0-5	7.35	7.41	7.49	7.57		
pH	5-10	7.49	7.78	7.76	7.72		
pH	10-15	7.37	7.54	7.73	7.58		
EC dS/m	0-5	0.19	0.18	0.26	0.24		
EC	5-10	0.18	0.19	0.21	0.21		
EC	10-15	0.14	0.15	0.20	0.19		
OC %	0-5	1.41	1.42	1.34	1.32		
OC	5-10	1.06	0.93	1.12	1.35		
OC	10-15	1.12	1.20	1.18	1.36		
Rosthern							
pH	0-5	6.55	6.50	6.50	6.55		
pH	5-10	6.45	6.27	6.51	6.39		
pH	10-15	6.37	6.30	6.53	6.49		
EC dS/m	0-5	0.20	0.19	0.17	0.18		
EC	5-10	0.14	0.15	0.14	0.14		
EC	10-15	0.13	0.14	0.15	0.15		
OC %	0-5	2.81	2.94	2.80	2.91		
OC	5-10	2.68	2.68	2.47	2.61		
OC	10-15	2.72	2.74	2.76	2.82		
Tisdale							
pH	0-5	6.71	6.60	6.57	6.49		
pH	5-10	6.45	6.44	6.55	6.64		
pH	10-15	6.31	6.37	6.53	6.49		
EC dS/m	0-5	0.30	0.27	0.21	0.20	1%	0.04
EC	5-10	0.15	0.16	0.14	0.13	1%	0.02
EC	10-15	0.15	0.17	0.15	0.15		
OC %	0-5	4.19	3.52	3.37	3.53		
OC	5-10	2.93	2.76	2.47	2.23		
OC	10-15	3.32	3.01	3.03	3.01		

4.4 Soil fertility.

Tillage and fertilization can significantly affect the amount of available N in the soil (Havlin et al., 2005). The tillage treatments in 2004 and 2005 resulted in evidence of increased net mineralization of NO_3-N in the form of higher NO_3-N concentrations at Central Butte. Reduced NO_3-N concentrations with tillage at Rosthern and Tisdale show evidence of immobilization (Table 5). This may be explained by the cropping history and the amount of reside that was incorporated during the tillage operations. Schoenau and Campbell (1996) noted that incorporation of large amounts of residues of high C:N ratio before seeding increased immobilization and reduced available N to the crop. Franzluebbers et al. (1995a) noted that the type, placement, and timing of residue input significantly alters the seasonal dynamics of the active soil C and N pools and the subsequent effect on N availability. At the Central Butte site there was only a small amount of weathered residue and thatch left from the 2003 cropping year due to the chemical fallow period in 2004. Chemical fallow straw is not expected to immobilization large amounts of N (Gares and Schoenau, 1995), and the result of increased aeration and microbial activity due to tillage would be to accelerate the mineralization of humus. The Rosthern and Tisdale sites had large amounts of fresh cereal residue left from the 2004 crop year. The high C:N ratio, and the amount of C incorporated, was enough to cause the microbial biomass to immobilize the available NO_3-N and reduce NO_3-N concentrations in the surrounding soil (Table 6).

Table 6 Nitrate (NO_3-N) concentrations measured in intact segmented cores taken after imposition of tillage treatments.†

Treatment	Central Butte			Rosthern			Tisdale		
	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm
	Spring 2005								
	mg kg^{-1}								
NT	10.15	5.25	4.90	16.58	8.30	10.94	24.08	10.85	10.63
MT	11.15	5.43	5.35	17.93	12.00	14.18	21.43	11.50	10.35
CT	20.88	11.98	10.20	11.35	9.98	10.16	13.38	6.90	7.73
MXT	12.50	8.80	6.25	12.60	10.93	11.39	13.15	7.28	7.00
LSD$_{(0.10)}$	**4.56**	**2.35**	**3.23**	**3.51**	**2.00**	**NS‡**	**4.61**	**2.71**	**1.67**
	Fall 2005								
NT	4.57	3.24	2.69	7.92	5.09	3.54	11.37	5.92	4.82
MT	5.91	4.48	3.23	8.59	5.86	4.16	8.97	5.69	3.85
CT	5.62	4.69	4.06	7.19	6.26	4.03	7.87	6.10	4.44
MXT	6.77	6.35	5.34	9.11	7.02	4.43	6.77	5.95	3.53
LSD$_{(0.10)}$	**NS**	**1.20**	**1.58**	**NS**	**NS**	**NS**	**2.81**	**NS**	**NS**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at $\alpha = 0.10$

Problems with P stratification have been common in long-term NT soils and tillage has been proposed to reduce nutrient stratification (Essington and Howard, 2000; Hussain et al., 1999; Zibilske et al., 2002). All three test sites demonstrated some P stratification in the NT treatment with concentrations of extractable P in the 0 to 5 cm

depth that were almost three times the concentrations at the 10 to 15 cm depth. Sampling of the treatments after the imposition of tillage in the spring of 2005 showed that tillage, particularly the MXT treatment, has some effect on reducing P stratification at all the experimental sites (Table 6). The soil characteristics and the degree of the mechanical mixing associated with tillage equipment would have a major effect on the extent of the increase in P concentration in the lower soil depths and the degree to which the P concentration is homogenized among the soil depths. Essington and Howard (2000) found that in NT soils the compact band of fertilizer P that is applied may slow conversion of P to less soluble forms of P. Tillage at each of the sites may have also reduced the labile P concentration in the soil because of increased mixing by tillage reducing the concentration around the fertilizer band and increasing the contact of fertilizer P with soil constituents responsible for P fixation. The fall 2005 soil P extraction showed slightly lower amounts of P compared with the spring NT soil extractions (Table 7). This reduction of P in the soil is probably due to P removal by crop growth.

As with P, stratification of K in long-term NT soils can become a problem. Potassium that is released and leached from the surface crop residues becomes adsorbed on to soil colloids resulting in accumulation of labile K on the soil surface (Crozier et al., 1999; Havlin et al., 2005; Robbins and Voss, 1991).

Table 7 Modified Kelowna extractable phosphorus concentrations measured in intact segmented cores taken after imposition of tillage treatments.†

Treatment	Central Butte			Rosthern			Tisdale		
	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm
	Spring 2005								
	mg kg^{-1}								
NT	27.54	16.72	8.76	29.32	19.50	10.94	44.82	24.73	10.00
MT	23.33	17.24	6.96	28.50	23.81	14.18	38.72	31.09	12.07
CT	24.58	18.20	9.64	22.08	19.54	10.16	32.56	22.58	11.39
MXT	26.35	21.42	11.55	25.61	21.86	11.39	35.13	20.61	14.56
$LSD_{(0.10)}$	**NS‡**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	Fall 2005								
NT	21.55	13.10	7.21	22.88	16.28	8.89	34.15	14.53	9.09
MT	24.08	16.05	6.71	24.20	14.60	10.54	31.83	17.44	7.27
CT	20.90	16.60	8.77	19.78	15.63	8.11	28.78	15.08	8.21
MXT	25.48	21.58	12.45	19.48	15.53	8.79	29.95	17.23	9.40
$LSD_{(0.10)}$	**NS**	**5.46**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at $\alpha = 0.10$

Stratification of K is evident at all the test sites in the 3 to 4 times higher concentrations of extractable K in the upper levels of the NT control tillage treatments as compared to the 10 to 15 cm soil segments (Table 7). After the tillage treatments, a general decrease in the 0 to 5 cm soil segment K concentrations, with K concentration increases in the 5 to

10 cm and the 10 to 15 cm soil segments provide evidence that tillage reduces K stratification.

4.5 Long-term effects on soil properties

Soil fertility was measured again in the spring of 2007 (Tables 8, 9, and 10). The data shows that there is no lasting effect of the tillage treatments on soil N, P, and K, neither on soil pH, EC, and Organic Carbon. There were also no effects on particulate organic matter, or on nutrient stratification. However, there were trends in the data showing that some of the effects had persisted albeit no longer significantly.

Soil nitrates in the 0-15 cm depth tended to be increased due to tillage treatment at Central Butte, but the opposite effect was evident at Tisdale. Particulate Organic Matter (POM), considered a more sensitive parameter for measuring OC turnover in soils showed a trend amongst treatments. Tillage had appeared to increase POM at Central Butte and appeared to decrease POM at Tisdale. Thus the effect of tillage resulting in nitrification at Central Butte had disappeared by the 3rd year. Similarly the effect of tillage on immobilizing soil N had also disappeared by the 3rd year.

Nutrient stratification also showed a trend, with tillage having reduced stratification of P and K at central Butte and at Tisdale.

Table 8. Soil analysis Spring 2007 at Central Butte

Depth cm		NO_3-N kg/ha	NH_4-N kg/ha	P kg/ha	K kg/ha	pH	EC dS/m	% OC	% OC POM
(0-5)	NT	3.5	3.8	16.2	325	7.53	0.13	1.54	0.86
	MXT	8.0	3.3	18.1	349	7.53	0.16	1.52	0.92
	MXT 2	15.2	3.6	18.7	337	7.46	0.41	1.39	1.09
	MT	13.2	3.4	14.9	306	7.23	0.17	1.49	1.05
	$LSD_{0.05}$	6.5	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
(5-10)	NT	3.9	3.8	7.3	179	7.43	0.14	1.12	
	MXT	7.7	3.6	8.8	204	7.91	0.43	1.02	
	MXT 2	9.9	3.9	7.0	189	7.58	0.18	1.19	
	MT	5.8	3.7	7.9	202	7.56	0.14	1.02	
	$LSD_{0.05}$	2.8	N.S.	N.S.	N.S.	N.S.	0.21	N.S.	
(10-15)	NT	6.1	3.9	4.8	151	7.56	0.15	1.12	
	MXT	9.4	3.6	8.3	199	7.55	0.20	1.22	
	MXT 2	9.3	4.0	9.5	192	8.02	0.44	0.95	
	MT	8.3	3.6	5.6	202	7.34	0.13	1.16	
	$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	

Table 9. Soil analysis Spring 2007 at Rosthern

Depth cm		NO_3-N kg/ha	NH_4-N kg/ha	P kg/ha	K kg/ha	pH	EC dS/m	% OC	% OC (POM) POM
(0-5)	NT	4.5	4.1	17.1	382	6.75	0.14	3.00	2.57
	MXT	3.3	4.0	12.2	305	6.75	0.13	2.99	2.33
	MXT 2	2.3	3.9	13.1	344	6.72	0.12	2.78	1.93
	MT	2.4	4.1	16.0	284	6.71	0.13	3.42	2.39
	$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
(5-10)	NT	4.3	4.0	5.6	173	6.40	0.11	2.39	
	MXT	4.2	3.9	4.7	115	6.45	0.10	2.41	
	MXT 2	3.4	4.0	5.6	119	6.44	0.10	2.45	
	MT	4.3	3.9	9.3	181	6.45	0.10	2.63	
	$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	
(10-15)	NT	4.9	3.9	6.3	167	6.45	0.11	2.43	
	MXT	4.1	3.8	5.0	144	6.46	0.10	2.42	
	MXT 2	3.7	4.0	4.8	97	6.47	0.10	2.39	
	MT	4.4	4.0	6.1	132	6.35	0.09	2.52	
	$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	

Table 10. Soil analysis Spring 2007 at Tisdale

Depth cm		NO_3-N kg/ha	NH_4-N kg/ha	P kg/ha	K kg/ha	pH	EC dS/m	% OC	% OC (POM) POM
(0-5)	NT	12.4	3.8	16.7	462	6.69	0.18	4.49	7.59
	MXT	13.1	5.1	15.8	450	6.54	0.18	3.69	6.54
	MXT 2	9.4	4.6	17.9	523	6.64	0.16	4.04	6.38
	MT	6.1	3.3	26.1	410	6.41	0.14	2.99	4.42
	$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
(5-10)	NT	6.0	4.8	3.5	245	6.64	0.11	2.73	
	MXT	5.9	5.3	5.7	214	6.47	0.11	2.41	
	MXT 2	5.8	4.1	5.2	204	6.68	0.11	1.58	
	MT	3.1	3.5	11.0	248	6.42	0.11	2.82	
	$LSD_{0.05}$	1.5	1.5	4.4	N.S.	N.S.	N.S.	N.S.	
(10-15)	NT	4.7	4.1	4.3	235	6.68	0.11	2.96	
	MXT	4.1	5.2	5.0	220	6.50	0.11	2.49	
	MXT 2	4.7	4.5	4.3	238	6.67	0.12	2.51	
	MT	2.9	3.9	8.9	173	6.42	0.10	1.53	
	$LSD_{0.05}$	N.S.	N.S.	3.65	N.S.	N.S.	N.S.	N.S.	

Soil physical properties measured in 2007 are shown in Table 11. Any differences that were apparent early on following tillage had disappeared in 2007.

Tabe 11. Soil Physical properties in the spring of 2007.

	SWC (v/v) (0-5 cm)	BD Mg/m3 (0-5 cm)	AFP (%) (0-5 cm)		SWC (v/v) (5-10 cm)	BD Mg/m3 (5-10 cm)	AFP (%) (5-10 cm)
Central Butte							
NT	33.2%	1.47	11.4%		34.2%	1.545	7.5%
MT	25.2%	1.35	23.8%		32.0%	1.496	11.5%
MT 2	35.4%	1.47	9.1%		38.1%	1.585	2.1%
CT	37.6%	1.49	6.1%		35.7%	1.550	5.9%
MXT	32.9%	1.47	11.7%		34.7%	1.480	9.4%
MXT 2	24.4%	1.36	24.5%		32.5%	1.481	11.6%
LSD0.05	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.
Rosthern							
NT	35.5%	1.34	13.8%		32.4%	1.26	20.1%
MT	29.6%	1.20	25.0%		33.0%	1.29	18.5%
MT 2	36.1%	1.38	11.7%		33.9%	1.31	16.7%
CT	35.8%	1.33	13.9%		33.2%	1.28	18.3%
MXT	34.1%	1.34	15.4%		32.5%	1.28	19.3%
MXT 2	30.6%	1.30	20.4%		32.0%	1.25	20.9%
LSD0.05	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.
Tisdale							
NT	38.6%	1.19	16.6%		36.6%	1.35	12.6%
MT	30.9%	1.19	24.0%		36.3%	1.34	13.2%
MT 2	39.3%	1.24	13.8%		36.2%	1.32	13.9%
CT	39.6%	1.25	13.0%		37.7%	1.40	9.4%
MXT	39.2%	1.25	13.7%		37.4%	1.43	8.8%
MXT 2	32.1%	1.31	18.3%		37.1%	1.37	11.1%
LSD0.05	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.

4.6 Effect on crop production

Grain yields, straw yields and total biomass production at all three sites for three seasons (2005, 2006 and 2007) are shown in Table 12. During the first field season following the tillage treatments, there were only small differences in crop production attributable to tillage. There were no effects due to tillage at Central Butte. A difference in grain production occurred at Rosthern and may be attributed to greater amounts of available N ultimately produced in the MXT treatment. The MXT treatment at Rosthern produced from 100 to 400 kg ha^{-1} more grain than the other tillage treatments possibly due to mineralization of organic matter. This is supported by the NO_3-N being the highest in the fall MXT treatment. Lower grain yield in the MT and CT treatments at Tisdale may be due to immobilization of NO_3-N in the spring. Reduced availability of N and P at the Tisdale site early in the season may have had a negative impact on yield.

The 2006 and 2007 crops did not shown any effects due to tillage. This consistent result firmly indicates that the effect of one cycle of tillage has minimal effect on crop production, that is only apparent in the first year following tillage.

The effect of tillage treatment on plant uptake of N & P is shown in Table 13. Except for the Tisdale site, there were no effects of tillage on plant N & P uptake. At Tisdale, tillage resulted in reduced N & P uptake by the crop in 2005. This is consistent with the immobilization effect of tillage discussed earlier.

Table 12. Effect of tillage treatments on crop production in 2005, 2006, and in 2007.

	2005 Crop			2006 Crop			2007 Crop		
Treatment	Grain	Straw	G&S	Grain	Straw	G&S	Grain	Straw	G&S
	(---- Mg ha^{-1}----)			(---- Mg ha^{-1}----)			(---- Mg ha^{-1}----)		
	Central Butte								
NT	2.43	4.02	6.85				2.40	2.85	5.25
MT	2.44	4.38	6.82				2.23	3.77	6.01
CT	2.38	4.15	6.52				2.21	3.62	5.83
MXT	2.46	3.72	6.17				2.62	4.30	6.92
MT-2							2.63	4.37	7.00
MXT-2							2.36	3.81	6.16
$LSD_{(0.05)}$	N.S.	N.S.	N.S.				N.S.	N.S.	N.S.
	Rosthern								
NT	1.70	3.37	5.81	3.29	3.00	6.58	1.98	3.55	5.53
MT	1.95	3.95	5.90	3.20	2.99	6.40	1.61	3.02	4.63
CT	1.73	3.49	5.97	3.16	3.10	6.32	1.68	3.21	4.89
MXT	2.13	4.36	6.49	3.26	2.65	6.52	1.77	3.44	5.22
MT-2							1.64	3.09	4.73
MXT-2							1.79	3.41	5.20
$LSD_{(0.05)}$	0.36	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Tisdale								
NT	1.77	4.32	6.10	1.92	2.72	4.63	1.88	4.44	6.31
MT	1.17	3.71	4.88	1.92	2.65	4.58	1.82	4.33	6.16
CT	1.38	4.19	5.57	2.06	2.61	4.68	1.34	3.24	4.58
MXT	1.64	4.15	5.78	2.24	3.15	5.39	1.71	3.58	5.29
MT-2							1.88	4.26	6.14
MXT-2							1.75	4.03	5.78
$LSD_{(0.05)}$	0.22	N.S.	0.63	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Crop rotations:

Central Butte: 2005 Wheat, 2006 Chem. Fallow, 2007 Wheat
Rosthern: 2005 Canola, 2006 Wheat, 2007 Wheat
Tisdale: 2005 Canola, 2006 Wheat, 2007
Wheat

Table 13. Effect of tillage treatments on N and P yields.

Treatment	2005 Crop		2006 Crop		2007 Crop	
	N	P	N	P	N	P
	(---- kg ha^{-1}----)		(---- kg ha^{-1}----)		(---- kg ha^{-1}----)	
Central Butte						
NT	64.8	11.3			52.7	9.1
MT	69.4	11.0			48.6	8.8
CT	61.6	11.3			48.9	8.4
MXT	66.9	10.8			61.5	9.7
MT-2					56.6	9.8
MXT-2					54.6	8.6
$LSD_{(0.05)}$	N.S.	N.S.			N.S.	N.S.
Rosthern						
NT	60.9	15.4	45.4	9.7	57.9	13.5
MT	70.9	15.4	48.9	9.7	47.2	11.3
CT	57.3	14.5	42.7	9.0	48.1	11.1
MXT	77.0	16.0	47.0	9.4	52.2	12.3
MT-2					48.6	11.0
MXT-2					51.1	12.0
$LSD_{(0.05)}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Tisdale						
NT	69.6	15.3	39.2	6.8	56.2	12.0
MT	52.1	11.5	37.9	6.7	52.7	11.4
CT	52.7	13.9	41.8	7.3	38.9	8.5
MXT	61.6	14.3	42.8	7.4	49.5	10.7
MT-2					54.1	11.7
MXT-2					51.3	11.0
$LSD_{(0.05)}$	9.0	2.0	N.S.	N.S.	N.S.	N.S.

5. Summary and Conclusions

This study examined the effects of a strategic tillage operation (cycle) imposed on a NT soil. The result shows that application of a tillage cycle has a limited effect on the soil chemical and physical properties as a whole. Tillage reduced nutrient stratification in surface soils, which was shown in the extractable P and K as they are less mobile in the soil. However, the overall effect on P and K availability to the crop was minimal. Tillage also affected spring soil temperatures during the spring following the tillage treatments, as surface temperatures generally increased with increased tillage. In cool

springs this may allow the producer quicker access to the field due to increased evaporation rates preparing the soil for an earlier seeding date.

When considering tillage, producers will have to take into account the impact of residue incorporation. The Rosthern and Tisdale sites showed evidence of NO_3-N immobilization due to incorporation of large amounts of straw with wide C to N ratios. If producers expect to incorporate large amounts of N-poor residues, they should take this into account when calculating their fertilizer requirements and possibly increase the amount of N-fertilizer applied to offset the immobilization effect of the SMB.

In terms of net effects of the tillage regimes on grain yield, tillage at the Central Butte site did not have a significant effect on yields, while at Rosthern there was a higher yield in the MXT treatment that may be related to the process of mineralization. At the Tisdale site some of the tillage treatments had reduced yield compared to NT, possibly due to N-immobilization. Overall the effects were not large and differences in responses at the different sites suggest that a large number of interacting factors ultimately affect the crop yield.

Carbon sequestration and retention is important if agricultural soils are to be considered a net C sink in the environment. This study found that there were no significant losses in total soil organic carbon (TOC) or particulate organic matter (POM) amounts in the 0 to 10 cm soil layer after one cycle of tillage was imposed on the NT soil. There were trends in the data, and these were still apparent in 2007. This suggests that the effect of tillage on soil properties and crop production may be more significant following a number of years of annual tillage operations, as opposed to a single cycle, even

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Appendix A. Tillage operations

Central Butte Brown Soil Zone

Rosthern Black Soil Zone

Tisdale Dark Gray Soil Zone

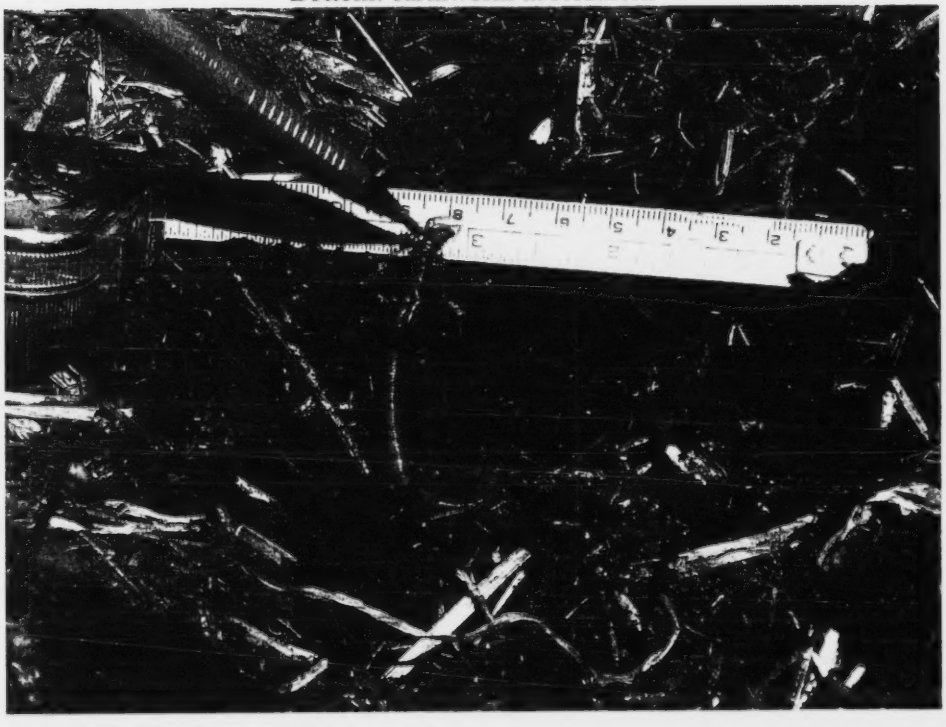
Appendix A (Continued). Photographs of Disturbance of surface residues

Top. Tilled field

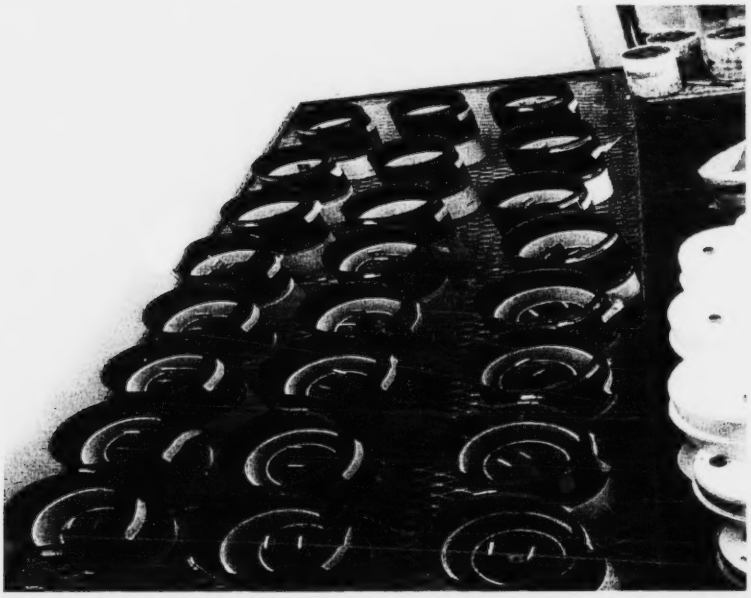
Bottom: Control (No-Till)

Top: Max Tillage

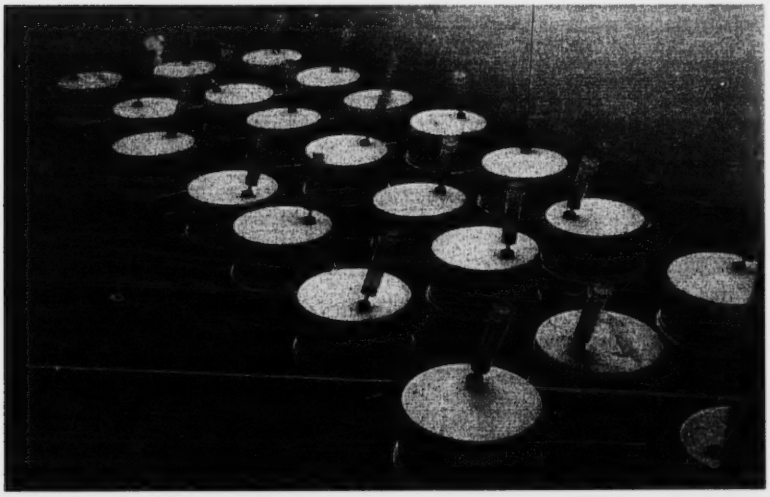
Bottom: earthworm at Rosthern



Appendix B: incubations and CO_2 chambers

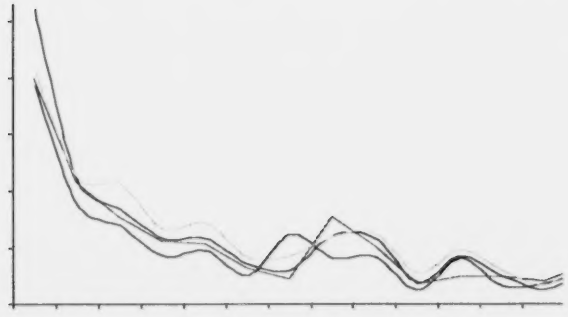


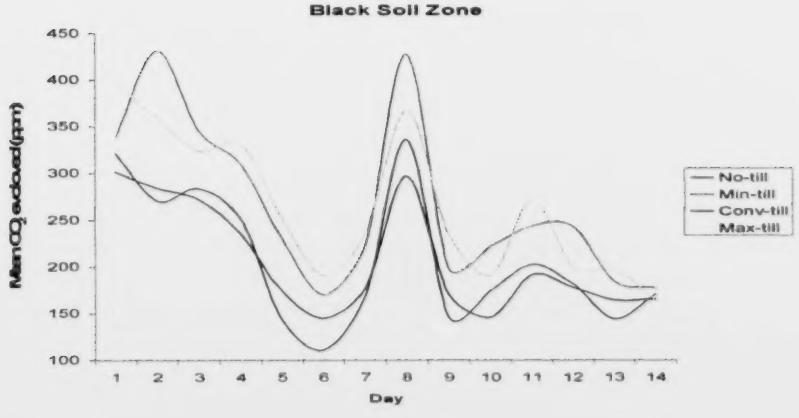
Top picture: incubation chambers containing intact PRS probes.

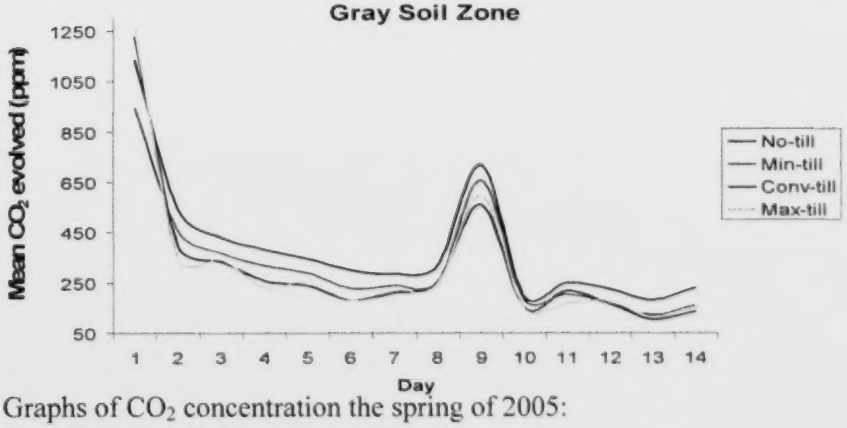


Bottom: CO_2 chambers for gas sampling

Appendix C: CO_2 evolutions







Graphs of CO_2 concentration the spring of 2005:
Top: Brown Soil Zone (Central Butte)
Middle: Black Soil Zone (Rosthern)
Bottom: Dark Gray Soil Zone (Tisdale)

Appendix D
Administrative and Other Aspects

Meetings where this project was presented

1. C.D. Baan, M.C.J. Grevers and J.J. Schoenau. Effects of Imposing Tillage on Long-term No-till Soils. 2006 Soils and Crops Workshop. Saskatoon, SK. Feb 16-17, 2006
2. C.D. Baan, M.C.J. Grevers and J.J. Schoenau. Effects of Imposing Tillage on Long-term No-till Soils. Annual Meeting of the Canadian Society of Soil Science, Banff, ALTA. May, 2006.
3. C.D. Baan, M.C.J. Grevers and J.J. Schoenau. Imposing Tillage on Long-term No-till Soils. 2008 Soils and Crops Workshop. Saskatoon, SK. Mar 14-15, 2008

Personnel involved in the project.
Tom King was hired on a casual basis to help with the tillage work and some of the laboratory analysis.

Casual help were hired for brief periods of time throughout the duration of the project to help with taking soil samples and plant sample harvesting and with chemical analyses.

Chris Baan (graduate student) worked full-time on this project as a graduate student stipend for the period of September 1, 2004 to December 31, 2006, as per the University of Saskatchewan stipends for M.Sc. graduate students.

Photographs of the experiment
Photographs are shown in Appendix A and B

Inventory of Canadian Agri-Food Research (ICAR).
This project was listed on the ICAR system (ICAR ID 33330859), and was updated in July of 2005, 2006 and 2007.

Expense Statement.
A complete expense statement will be sent by the Univ. of Saskatchewan Financial Services.